12. HIGH AND LOW VOLTAGE SYSTEMS

12.1 HIGH VOLTAGE SYSTEMS

12.1.1 Barrel and endcap photodetectors

Requirements

Photodetectors for the barrel and endcap calorimeters are hybrid photomultiplier tubes (HPD). HPDs are a specific variant of image intensifier technology in which an array of silicon diode pixels is placed in close proximity to the photocathode. As described in chapter 8, gain is due to the kinetic energy gained by photoelectrons from the applied acceleration field between the photocathode and the silicon anode. High voltages in the range 12 kV to 15 kV result in photoelectron gains in the range 2000 to 3000.

The photoelectron current drawn by the tube is extremely small. In the region with the highest energy particle flux, close to the beam pipe in the endcap calorimeter, this current amounts to only 20 pA per pixel or about 400 pA for a 19 pixel tube. At the quietest point, the midpoint of the barrel calorimeter at 90° polar angle, the photocurrent is a factor of 8 lower. The maximum current needed is 2 nA when all five HPD tubes in a given readout box are connected to a single high voltage power supply.

Since gain in an HPD device is linear with the applied high voltage, gain stability does not impose severe requirements on power supply stability. The requirement is that gain variations due to high voltage power supply changes should be less than 1% . The linear gain-voltage relationship implies a corresponding power supply voltage stability that is also good to better than 1%.

The HPD diode pixel array must be reversed biased into full depletion in order to collect the ionisation each incident photoelectron. Depletion occurs for a back bias potential of 50 to 70 volts. Applying a higher field improves the timing response, and values in the 100 to 150 volt region are typically used with these photodetectors, since the signal comes from hole motion.

At a gain of 2000, the HPD diode current resulting from beam-beam interactions is significantly smaller than the current produced by the device itself in the absence of photon irradiance. This dark current is 1 to 5 nA per pixel initially and comes entirely from bulk leakage processes in the silicon. Neutron irradiation creates defects in the bulk material leading to an increase in leakage current which is linear with dose, 20 nA/10^{10} neutrons/cm^2 has been measured (chapter 8.2). For the largest diode area, 24 square mm, and a worst case predicted lifetime neutron exposure, $5x10^{11}$ per cm^2, the leakage current increases to some 24 nA. Allowing for uncertainty in the radiation exposure estimate, the bias power supply maximum current requirement for a 19 pixel tube is 2 μA.

Bias voltage only depletes the silicon and influences the impulse response behaviour. It is not involved in determining the gain. Consequently, voltage stability is not an important parameter.

For both the high voltage and the bias voltages, noise and ripple are very important parameters. Any AC signal on the voltage supplies is capacitively coupled directly into the readout and is coherent over the entire pixel array. For this reason the voltages are well bypassed right at the HPD pinouts. Overall, the noise floor goal is 3000 electrons rms, or 0.48 fC, per pixel (chapter 9). This requirement implies a bias voltage noise floor smaller than

100 μV rms for the 5 pF pixel capacitances involved. For high voltage, the coupling capacitance between the photocathode and an anode pixel is a factor of 30 smaller making the noise floor limit 3 mV rms. The noise floor requirements apply to the overall system; power supplies, power leads, and local filter stages. Essentially, whatever noise level is introduced by the power supplies and through pickup in the connections must be reduced to acceptable levels by filter stages at the photodetector interfaces.

Overcurrent protection is necessary to protect the system. A fast voltage trip function triggered by a sudden increase in current should shut down the supply and discharge the cable. This type of protection is found on all wire chamber high voltage supplies. For HPDs, the fast trip is needed on both the high voltage and the bias supplies. The HPD voltage supply requirements appear in Table 12. 1.

Table 12. 1
HPD Power Supply Requirements.

	High Voltage	**Bias Voltage**
Voltage	12-15 kV	100-150 V
Stability	< 1%	< 10%
Current	2 nA	2 μA
Noise	< 3 mV	< 100 μV
Fast Trip	yes	yes

System overview

Power supplies for the high voltages and bias voltages are located in the shielded service room adjacent to the detector cavern to eliminate concerns about radiation exposure effects and accessibility. However, noise considerations dictate the system grounding and return path parameters. A single point safety ground connection for the power supply and readout systems is envisioned to eliminate any possibility of a DC ground loop vulnerability. This configuration rule must also include the low voltage power supplies for the front-end electronics which are located along the side galleries of the detector cavern. Supply outputs are differential and have a single-point, common safety ground at the readout boxes.

One high voltage supply and five bias sources are packaged as a 6U VMEbus card; one such module is needed for each HPD readout box. VME was selected to make the interface to the Detector Control System as natural and simple as possible. The VME crate(s) are located in the underground service room where repair and maintenance access is straightforward; the cable runs are then about 150 meters long.

High voltages are brought to the photodetectors using twisted-pairs with an overall shield. The shield is hard grounded at the readout box and AC terminated at the supply to minimise EMI. A single high voltage supply services all of the HPDs in a given readout box for cost reasons. However, each photodetector is connected individually; there is one pair in the cable per HPD to avoid a single point failure which could take out an entire readout box. To be in compliance with CERN policy on the use of plastics in underground enclosures, the pairs will have silicon rubber insulation. Derating the dielectric strength of silicon rubber to 30 kV/mm implies an insulation thickness of 0.3 mm for 16 kV service. Thus, the cables are quite small and flexible. A custom connector is planned which has wiping contacts similar to banana jacks.

Additional pairs in the cable bring the bias voltage to each HPD in the readout box. In this case, individual supplies for each HPD are necessary to allow for the (potential) individual characteristics and ageing behaviour of the diode arrays.

Assembly and installation

The high voltage supplies are based on commercial DC-to-DC converters; night vision devices use such converters making them readily available. At this time, it is not known whether a commercial noise filter unit exists or whether development is required. A custom fast trip circuit is needed as none are available for the 16 kV operating point. An adaptation of one often used trip circuit design involving sensing the return current will be undertaken. The same custom connector used at the load end of the cable will be used at the supply end.

Bias voltages will be derived from a DC-to-DC converter also; at a working point of 150 volts, commercial noise suppression devices are available. Subsequent individual regulator stages allow for separate control and monitoring of the bias for each HPD separately.

Whether assembly is done commercially or at one of the collaborating institutions is not yet decided. The system comprises 120 modules plus spares and 7 VME 6U powered crates; 120 high voltage cables are also needed. Installation involves placing crates and racks in the service room and laying cable from there to the cavern and the individual readout boxes.

Quality control, assurance, and monitoring

The QA/QC process that will be followed has three steps. First, the set of requirements is developed and approved by technical management. R&D is then carried out to develop a design proposal and a rough cost and schedule outline which are reviewed against the requirements. Third, a detailed plan of work, a complete schedule with appropriate milestones, and a very detailed cost breakdown are prepared. These items are then used to monitor and guide the manufacture and for reporting to oversight groups.

For fabrication of power supplies, especially high voltage units, testing of completed assemblies is not sufficient. Acceptance testing of the critical elements is necessary before assembly, and corresponding test stands are part of the project. Cable assemblies are tested twice, first at the fabricator and then after installation but before connection to the equipment.

Having the supplies packaged as VME modules makes monitoring a simple task. The Detector Control System extends to the VMEbus using an in-crate Input-Output-Controller. This processor continually monitors the voltage and current readings and transmits error messages for out of tolerance conditions or trips to higher levels of the system.

Access, maintenance, and operations

The high voltage supplies are VME modules located in the underground service room. Access for authorised personnel is straightforward should repairs be required. There are no maintenance requirements. Operations are controlled and monitored remotely using the Detector Control System.

12.1.2 Forward photodetectors HF

HF requirements

The HF uses standard dynode-multiplication photomultiplier tubes of at most 10 stages. The PMTs require high voltages (HV) up to at most 1.8 kV. In order to control the stable gain of the photodetectors, and to detect faults in the system, the HV system must provide the ability to: (a) control or "set" the voltage, (b) read back the voltage actually delivered to the devices, (c) monitor the current drawn, (d) provide overcurrent protection, and (e) provide sufficient current in such a fashion that the PMTs maintain high linearity.

An individual PMT requires at most 60 μA of anode current at 1.8 kV or 110 mW of HV power for direct amplification of photoelectrons for the HF. Additional power loss occurs as electrons in the dynode stages strike the dynode elements, a loss which appears in the form of heat. Typical upper limit for this loss is estimated at about 60 μA × 100 V at the anode, or 60 mW lost to heating. This is the case where HV power is used only to directly to bias the PMT dynodes.

The PMT must maintain current linearity within 2% from 0-60 μA average current, and from a peak pulsed current of 0-25 mA. Therefore, the PMT HV supply must maintain a current linearity similarly; i.e. it must maintain a linear current to 2% during the 1.5 ns risetime of the PMT and be able to support discharges at the 40 MHz rate of crossings without loss of linearity. To maintain these levels using a resistive dynode biasing circuit, the currents maintained by the HV supply must be ×100 larger.

For gain stability, since the gain $g \sim V^D$, where D = number of dynodes, then $\delta V/V \sim 1/D\ \delta g/g$. We impose a requirement that the gain g is stable to ±1%. Thus the voltage must be stable to <0.1% for a ten stage PMT. The HF PMT power supply requirements appear in Table 12.2.

Table 12. 2

HF PMT Power Supply Requirements.

High Voltage Max	1.2-1.8 kV
High Voltage Steps	#dynodes+1
Current, Average	100 μA
Current, Peak	25 mA
Slew Rate	100 V/μs
Ripple/Noise, p-p	100 mV
Stored Energy/Dynode	4 μJ
Current Monitor	yes, ± 1 μA
Current Trip	yes, <10 ms
Current limit	yes, 120 μA
Specific Power	>50 mW/cc
Voltage Setting Error	±1V
Stability	<0.1%

System description

The HF PMT will be negatively biased with a Cockcroft-Walton (C-W) type voltage capacitive multiplier which provides an individual fixed voltage ratio output for each dynode and the photocathode via the successive stages of the capacitive full-wave rectifier voltage multiplier ladder.[1-6] Fig. 12. 1 shows a typical C-W circuit produced commercially by Hamamatsu and used in HF testing. The circuit for HF would be similar to this. In this example of a C-W circuit, a self-oscillating sine-waveform power generator (180 kHz) is boosted by a transformer to up to 100 V, and fed into the multiplier. The feedback regulation uses a 1:1000 laser trimmed precision divider to compare the opposite sign reference control voltage to the generated HV to control the voltage applied to the power oscillator through a pass resistor. Typically the circuit consumes 100 mA @ 15 V to deliver 600 μA at 2 kV. The control voltage is 1 V/kV. The volume is <20 cc and the specific power >75 mW/cc. A typical temperature coefficient can be maintained at 100 ppm/C°.

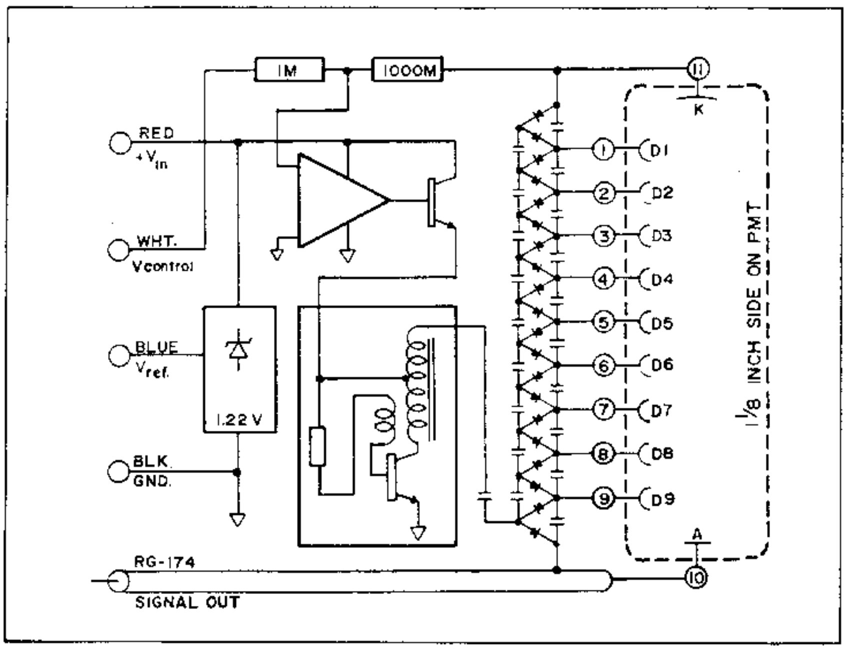

Fig. 12. 1: Cockcroft-Walton type active base/power supply.

These C-W base/supplies have been successfully used in experiments and have become commercially available. The great advantage in a C-W base is the large increase in linear dynamic range provided, due in part to the ability to isolate the voltages on the dynode chain from dynamic effects during the amplification process. It is this aspect that leads to the proposal of this type of bias circuit for the PMT in the HF calorimeter. Fig. 12.2 shows the increase in the linear PMT current possible with a C-W base, compared with a similar resistive base. Typically a factor of 10-20 in linear dynamic range can be obtained, and that helps to match an ordinary PMT to the task of the HF calorimetry at high rates. Additionally, power and ancillary heating of the PMT/base assembly is saved due to the absence of a resistive dynode chain.

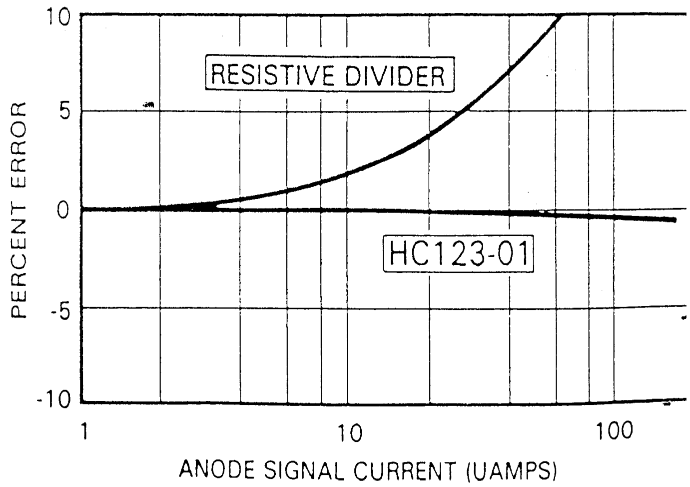

Fig. 12. 2: The linear PMT current possible with a C-W base/HV supply.

In a C-W base, the voltage level is determined by a low voltage oscillator which typically operates up to a few hundred kHz. Feedback circuitry is used to maintain voltage level. Careful attention to reducing pickup of the switching transients by the data signals will be needed.

A possible provision of the base/HV would be that the cathode-D1 voltage will be separately controlled from the voltage across the dynode chain, in order that the electron optics be separated from the gain section. At present this does not seem to be a necessity, but will be kept open as an option.

In an attempt to limit active components inside the HF shielding, to reduce cooling requirements at the PMT, and to increase the available space for shielding we plan to generate the HV for each dynode remotely from the PMT in a rack outside of the shielding. A bundle of 11 (# dynodes+cathode+ground) wires carry the HV for each dynode and cathode from HV crates located a few m from the HF itself. The “base” would thus consist only of a PMT socket, bypass capacitors for high frequency performance, a multipin HV connector, and at most a passive matching network for the anode signal coax. The current on each dynode HV cable is less than 1 mA, with the power at most a few mW on each conductor. With silicon rubber insulation, radiation hard to the ~Grad level, the HV multiconductor cable would be about 6 mm in diameter.

Assembly and installation

It is likely that the HV units will be based on commercial products. The individual components and sub systems are assembled as 32-channel VME modules in the 9U by 400 mm format. this modularity matches that of the 32-channel front end electronics VME modules. A semi-custom VME crate is required to provide the output connections to the photomultiplier tubes.

Whether assembly is done commercially or as one of the collaborating institutions has not been decided. The system consists of 128 high voltage modules plus spares and 8 powered VME 9U crates. Installation involves setting racks and crates on the detector platform, and connecting 2 meter-long cables from the back planes to the photomultiplier tube sockets through small openings in the HF shielding.

Quality control, assurance, and monitoring

The QA/QC process will be similar to that for HB and HE in that pre-assembly testing of certain components is needed. In addition to testing of completed asemblies before installation, a combined photomultiplier tube - high voltage unit longer term test is planned. This burn-in period is as least 48 hours and uses operating conditions at 100% of the voltage and current limit as established by a LED light flasher source operated at 40MHz.

Monitoring is straight forward as the Detector Control System extends to the VMEbus using a standard Input-Output-Controller. this processor continually monitors voltage and current values and transmits errors messages for out of tolerance conditions or trips to higher levels of the system.

Access, maintenance, and operations

The access to the HF high voltage system is straight-forward, since all of the racks are external to the shielding and readily accessible by authorized personnel during a routine access to the cavern.

12.2 LOW VOLTAGE SYSTEMS

12.2.1 Barrel and endcap electronics

Requirements

The front-end electronics for the barrel and endcap calorimeters described in chapter 9 are contained in individual readout boxes located on the outer surface of the absorber. Local power supplies or DC-to-DC converters cannot be used as the magnetic filed strength is 40 kilogauss at that location. Also, any components placed at the readout boxes must meet a difficult reliability requirement as described in chapter 9 for the electronics.

Each readout box requires +5 volts at 40 A and +10 volts at 6 A. Specifications for ripple and EMI/EMC (to be worked out during prototyping) will be very tight because of the low noise requirement on the electronics. Components of the low voltage system inside the readout box should introduce minimum additional heat load.

Radiation conditions at the location of the readout boxes is estimated at 10^{10} neutrons per square centimetre per year with about the same flux of gamma rays. Charged particle doses are negligible. Components for this location must be shown to withstand this level of irradiation. At the side galleries of the cavern, fluxes are about two orders of magnitude lower. Because of the well-known lack of radiation tolerance for some power supply components, validation is required for those systems as well.

Low voltage system

The topology for low power distribution is to use local low voltage, low drop-out linear regulators at the front-end electronics and place switching power supplies 30 meters away where the magnetic field is about 500 gauss. It is quite possible to shield the power supply transformers from such a field. Because of the reliability and noise floor requirements, each three channel module is equipped with two regulators, one for the digital section and one for the analog section. The power required for the three channel group of ASICs and optical link on each front-end board is estimated to be 3.25 W. The total power per box, including 48 boards and the regulators, is estimated to be about 210 W. Fig. 12. 3 and Fig. 12. 4 illustrate the proposed system.

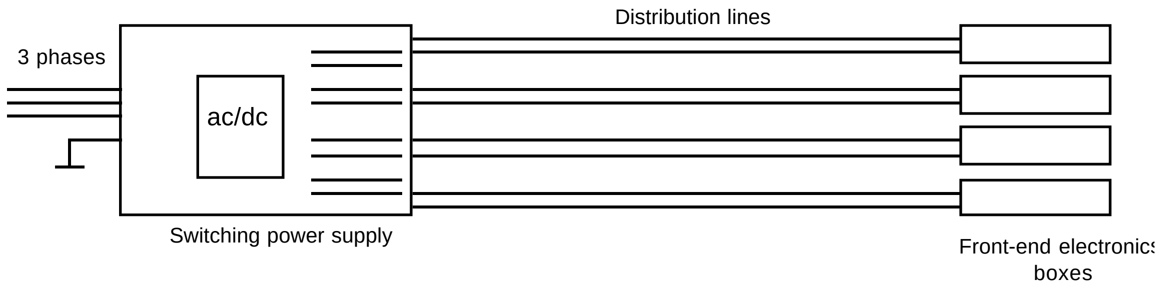

Fig. 12. 3: System Layout.

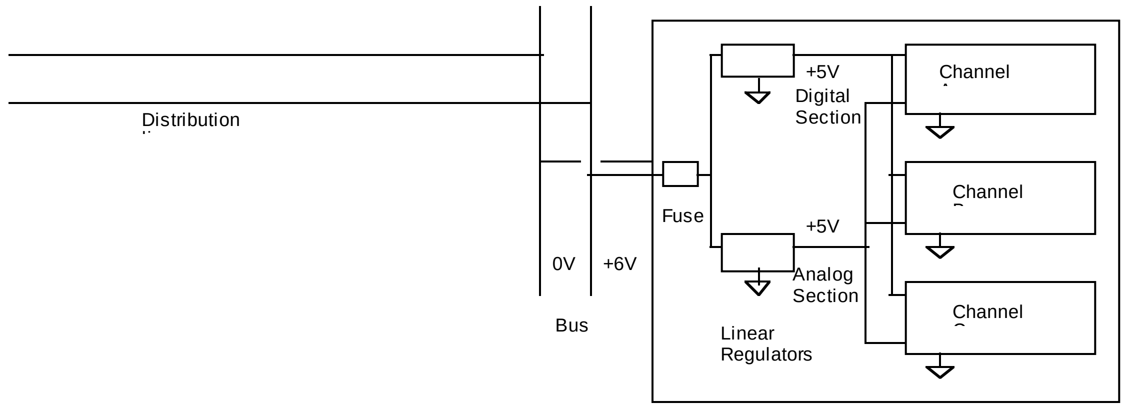

Fig. 12. 4: Front-End Module Power.

Each channel of front-end electronics is expected to have a single +5V power supply. Low drop out linear regulators are used to regulate this input voltage from a bus located in each box. A box is connected to 1/4 of a switching power supply main frame using water cooled copper conductors. Switching power supplies are configured as multiple modules connected in parallel to reach the current level required by the front-end electronics. They have a three phase input, a built-in AC-DC converter and eight modules rated up to 200 W. Two of them are connected in parallel at the output to feed the distribution cable. This commercial package has to be shielded from magnetic fields for proper operation.

The current required per front-end board is about 0.65 A. Linear regulators can be connected between the internal power bus and the analog and digital sections of the board separately. By using low drop out devices it is possible to keep the power dissipation in the regulator to a minimum. There are commercial devices with 5 V/0.75 A output which are appropriate for this application. They can handle input voltages up to +26 V and have a minimum input to output voltage drop of 600 mV. The output voltage of these devices is in the range +4.75 V to +5.25 V. Under these conditions, the minimum input voltage for proper operation of all devices is +5.85 V. These regulators have fold-back output current protection. Fuses rated at I > 0.85 A are necessary at each distribution point of the bus to protect the connector and input traces of each board. Snap-action resettable Poly-Fuse devices are proposed, but the radiation tolerance and magnetic field sensitivity parameters of these devices are not yet established.

The nominal current flowing through the distribution lines is about 35 A These lines are designed to avoid large voltage drop across them, which means the cross section is over-designed for such a current. These lines do not need current protection supplemental to that built in into the switching power supplies. Under any plausible fault condition, the maximum current that the power supply delivers is lower than the rated current capability of the wires. The voltage drop estimated for these conductors is about 0.8 V, or a total power loss of 600 W for HB and HE.

The switching power supply configuration consists of AC/DC converters at the input and DC/DC modules at the output. The output voltage required is about 7 V. The AC/DC converters take the three phase AC input power and performs filtering and rectification. The DC/DC converters plug into a high voltage back plane and provide low-noise, independently regulated and fully isolated outputs. The AC/DC converters are fully protected against loss of a phase, excessive loading, etc. This commercial package is cooled by a fan. It is necessary to include an air-water heat exchanger to avoid conducting heat into the cavern environment. Additionally, a magnetic shield has to be designed to protect those power supplies from the 500 gauss stray magnetic field.

Each power supply is connected to the three phase system and the chassis and the input ground is connected to the safety ground of the main AC distribution. Outputs can float allowing for a single point ground configuration for the readout boxes. This ground connection is made locally at each box.

Power cable and cooling

Power and cooling water services for the readout boxes have the following requirements:

a) No net heat into the local environment from cabling or electronics
b) Water flow of 1 liter/min
c) Water and power lead lengths about 30 meters
d) Nominal current of 40 A at +5V and 6 A at +10 V
e) Conductors are in a 4 T field
f) Voltage drop less than 1 V
g) Very high reliability inside the detector

Power and cooling water is brought to each readout box individually to avoid coupled failure modes. The configuration where a large supply is brought in and services are distributed locally through manifolds was not selected for reasons of reliability, ground loops and electrical protection. Flexible components have been selected to facilitate installation; multi-filament #3/0 AWG welding cables for the 5 volt supply and return and fibre reinforced power supply hose for the cooling water supply and return. The 10 volt service uses a pair of #10 AWG copper wires.

The power conductors will be twisted periodically and tied together at suitable intervals to accommodate the 4 T field forces present over the last few meters of the run.

The copper leads are pre-terminated at each end with high compression "copper only" cable lugs. At the ends, torqued connections will be made using belleville washers for high reliability and zero maintenance. The water lines are also terminated during manufacture with appropriate fittings for the supply and readout box couplings. There are several overpressure protection devices to prevent hose failure and subsequent leaks.

The line drop for the #3/0 copper cables is approximately 0.8 V which is within the specified requirements, and the drop on the #10 cable is about 0.2 V which is again an acceptable number. The heat dissipated by the leads is less than 8 watts; and no special cooling system is required. Inlet water temperature is set sufficiently below ambient temperature to have the return flow exit at ambient temperature. The net refrigeration to the cavern provided by this operating condition more than compensates for any heat dissipation into the air.

Acquisition and installation

Power supplies will be purchased by going to tender with appropriate specifications. These supplies will be semi-custom commercial units because the voltage needed is not very common in industrial applications. For economic reasons, we anticipate a CERN coordinated quantity acquisition which involves other subdetectors. Service, installation, and repair functions are simplified by such commonality as well. Installation into the relay racks is straight forward and can take place any time after the racks are installed and powered. Installation and connection of the conductors takes place quite late in the schedule. The central wheel muon detector system must be completed before any cables can be installed; and it is prudent to wait until the corresponding calorimeter assemblies have been installed to avoid damage.

Low voltage drop-out linear regulators are off-the-shelf commercial components. The specifications are for maximum and nominal electrical ratings and reliability. Installation is described in chapter 9 for the front-end modules.

Both the regulators and the power supplies must operate in a neutron and gamma ray radiation environment. In addition, there is a magnetic field present. The resistance of the product to this environment is typically information that industrial producers do not supply. Testing and validation is necessary before final selection can be made.

Quality control, assurance, and monitoring

The low voltage supplies are commercial units, the result of preparing a specification and going to tender. A semiautomatic test stand is needed for incoming inspection and verification of capabilities and EMC compliance. Sampling is not anticipated, all supplies will be checked.

It is probable that assembly of the water hoses and power leads will be put out for tender. In that case, QA/QC provisions will be included in the specifications. It is likely that QC for the materials used to construct the leads will be left to the vendor, but the QC plan will be required in the bid response. QA measures for the completed assemblies are part of the specifications in the bid package. Testing of both electrical and hydraulic characteristics is necessary, and the method of testing and the criteria will be specified by experienced engineers in the Fermilab magnet power supply and leads group.

After installation but before first use, the leads are to be rechecked for possible induced damage. A simple pneumatic test identifies leaky cooling hoses, and measurements of continuity, isolation and ground impedance identifies electrical faults.

Voltages, currents and temperatures are continuously monitored using the Detector Control System capabilities. Each power supply rack contains a local processor running a monitor and control task; ethernet is used for communication with the higher levels of the system. A fieldbus connection to the readout boxes brings back similar information from the far end of the power leads. Specific monitoring for EMI/EMC compliance is not necessary; the sensitive front-end electronics for the calorimeter and muon detectors will easily identify a noisy power supply condition.

The Detector Control System is also interfaced to the site utility plant, in particular to the chilled water system. Control and monitoring of the supply and return cooling water conditions is accomplished using this interface.

Commercial voltage regulator components have a yield of better than 99%. Therefore, tests of these devices will be at the board level as failure modes, even an input to output short, do not lead to damage of the other components on the board. Testing requires only that the output voltage is within specified limits.

Access, maintenance, and operations

Low voltage power supplies for the front-end electronics are located in racks along the side galleries of the cavern. Access by authorised personnel is possible, but is normally a scheduled activity due to the interruption in accelerator operations. Maintenance is not an issue; the supplies do not require servicing. Operations of the power supplies are controlled remotely using the capabilities of the Detector Control System.

For one third of their length, the water hoses and power leads are as accessible as the power supplies. For the remaining two thirds of the length, a major disassembly of the detector is required to provide a repair access. The majority of the trapped run calls for disassembly not only of the forward and endcap systems, but two of the return yoke wheels as well. The power lead terminations are designed to be maintenance free, and the water connections do not use quick-disconnect technology. The power leads are completely passive and have no operational impact.

12.2.2 Forward electronics

Requirements

The front-end electronics are packaged on printed circuit boards and housed in 9U VME crates. Standard VME power supply assemblies are required, and standard relay racks are used.

The stray magnetic field in the vicinity of HF is a few hundred gauss. Shielding of the power supply transformers may be necessary, but this is a standard procedure, e.g. the L3 experiment at LEP.

At the HF electronics racks location, the neutron fluence is predicted to be 10^3 per square centimetre per second. This corresponds to 10^{10} neutrons per square centimetre per year. The flux of gamma rays is of the same order of magnitude. Ionising doses are negligible, amounting to 100 rad per year. Power supplies must withstand these irradiations for the ten year operating period foreseen. Because of the well-known lack of radiation tolerance for some power supply components, validation is required.

Acquisition and installation

Power supplies will be purchased by going to tender with appropriate specifications. For economic reasons, we anticipate a CERN coordinated quantity acquisition which involves other subdetectors. Service, installation, and repair functions are simplified by such commonality as well. Installation into the relay racks is straight forward and can take place any time after the racks are installed and powered. Connection to cooling water systems will determine the schedule.

Quality control, assurance, and monitoring

The low voltage supplies are commercial units, the result of preparing a specification and going to tender. A test stand is needed for incoming inspection and verification of capabilities and EMC compliance. Sampling is not anticipated, all supplies will be checked.

Voltages, currents and temperatures are continuously monitored using the Detector Control System capabilities. Each crate contains a local processor running a monitor and control task; ethernet is used for communication with the higher levels of the system. Specific monitoring for EMI/EMC compliance is not necessary; the sensitive front-end electronics for the HF calorimeter will easily identify a noisy power supply condition.

The Detector Control System is also interfaced to the site utility plant, in particular to the chilled water system. Control and monitoring of the supply and return cooling water conditions is accomplished using this interface.

Access, maintenance, and monitoring

When the detector is in the garage position, the racks are easily accessible for any required maintenance or repair operations. Access is somewhat more difficult in the cavern as the calorimeter is some 8 meters above the floor level centered on the beam line. Specific personnel access techniques, stairs, catwalks, and lifting devices, have not been designed at this time, but are straightforward applications of well-known hardware. The stray magnetic field strengths expected, a few hundred gauss, would call for proper procedures, training, and equipment should a service access be made with the solenoid energised.

The residual radioactivity activity levels discussed in chapter 5. refer to the end of a ten year operating period. During commissioning and the early years of accelerator operation, activation will not be a problem and no restrictions on access to the electronics are expected. As the system grows more and more activated, there could be need for placing time limits on access or for temporary local shielding during maintenance operations. Therefore, the power supply system should feature good remote diagnostics to pinpoint problems and allow for simple replacement as the preferred method of repair.

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TABLE OF CONTENTS